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CERAMIC/METAL COMPOSITE CIRCUIT-BOARD-LEVEL TECHNOLOGY FOR APPLICATION SPECIFIC ELECTRONIC MODULES (ASEMs)

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TABLE OF CONTENTS

Summary

- The primary emphasis this past quarter was the demonstation of a reliable process for the mass fabrication a high density of electrical feedthroughs in the metal core.
- A low cost process for the mass fabrication of small (13 mil diameter) in a Cu/Mo/Cu metal has been demonstrated. To assure a high yield process, multiple layers of insulator formed, so that it is highly unlikely that a defect in one insulation layer will propagate to the next layer. The process relies on suction screen printing (a variation of standard via-filling by screen printing methods) to form a reliable insulator. The process forms electrical feedthroughs that are isolated from the metal core by $>10^9 \Omega$. Thermal shock testing (25 cycles) between -77°C and +150°C did not cause any opens in the feedthroughs, and the isolation from the metal core remained $10^9 \Omega$. Laser drilling the holes in the metal core shows great promise to greatly reduce both the drilling time and the cost of fabricating electrical feedthroughs.
- A glass ceramic, KU-4, was chosen to be the prime candidate for development of the green tape system for this project. KU-4 glass is a $MgO\text{-}Al_2O_3\text{-}SiO_2$ composition that readily crystallizes above 915°C. This glass is thermal expansion matched to the Cu/Mo/Cu (13/74/13 ratio) metal core and exhibits very low dielectric loss, making it an ideal substrate material for interconnecting bare Si and GaAs die in high speed digital and microwave circuits.
- A preliminary cost analysis was performed on the technology being developed during Phase I of this project. This analysis indicated that the high volume manufacturing of a single-sided, 6-layer LTCC-M substrate on a Cu/Mo/Cu metal core providing 200 inches/sq. in. of interconnect density will be about $1.43/sq. in.; in comparison, the low cost MCM-L technology would cost $1.50/sq. in. and still not provide a metal base for thermal management. Projecting to a 2-sided substrate having 6-layers on each side, a 400 inch/sq. in. interconnect density would cost about $2.39. This technology is well on target to meet ARPA's 1996 goal of producing interconnect substrates having an interconnect density of 1000 inches/sq. in. for $10/sq. in.

Section I
WBS Task 1.1: Metal Core Fabrication

A. TASK OBJECTIVE

The development of a process to fabricate many small electrical feedthroughs within the metal core. These feedthroughs must be fabricated with a very high yield, low cost process that offers high reliability and compatibility with the LTCC-M process technology.

B. INTRODUCTION

The development of a technology to fabricate many small electrical feedthroughs within the metal core is one of the central features of the Phase I research program. To obtain high reliability, the insulator in the hole must match the thermal expansion of the metal core (13/74/13 Cu/Mo/Cu clad laminate manufactured by Climax Specialty Metals). Phase I will concentrate on the fabrication of 13 mil diameter electrical feedthroughs, the smallest standard plated-through hole used by the printed wiring board industry. Smaller feedthroughs are possible using laser drilled holes in the metal core.

The basic feedthrough fabrication process involves opening up a hole (e.g. drilling and deburring), applying a layer of nickel to seal the molybdenum, depositing an annular ring of insulation, and finally depositing a conductor in the center core of the insulator. The conductor and insulator must be able to withstand several 900°C firing steps required to complete the LTCC-M fabrication process. For high module yields the insulator must be deposited above a minimum thickness and not contain large pinholes. After the hole has been formed, an insulating ring must be deposited, and finally the center conductor filled. During this past quarter, many insulator deposition techniques were investigated, and screen printing emerged as the best solution for mass production of electrical feedthroughs in the metal core. In this report the suction screen printing process will be described, and data will be presented showing the reliability of this process.

C. HOLE FABRICATION

For all of the metal core feedthroughs described in this quarterly report, the holes in the Copper/Molybdenum/Copper (Cu/Mo/Cu) metal core were formed using standard numerically controlled, mechanical drilling machines. The focus of the work was to drill 13 mil diameter holes and then deburr using a soft stone. This produced holes having sharp corners. It was also noted, that it was significantly more difficult to drill 13 mil holes in 40 mil thick Cu/Mo/Cu, compared to drilling 20 mil thick metal cores. After deburring, these holes are Ni-plated by electrolytic methods. Cross sections (shown later in this report) show the Ni-plate to be quite uniform in the hole.

Experiments were also performed using a laser to drill holes in Cu/Mo/Cu metal cores. Holes were drilled by Coherent General (Sturbridge, MA) using a Nd:YAG laser at 15-30 watts, with 0.6 msec. pulse lengths. 13 mil diameter holes could be readily drilled in both 20 and 40 mil thick Cu/Mo/Cu. The minimum hole

diameter was 7 mils for 20 mil thick Cu/Mo/Cu and 8 mils for 40 mil Cu/Mo/Cu. After drilling a "slag" residue remained around the perimeter of the laser drilled holes, this could be removed by mechanical means.

Next quarter, electrical feedthroughs will be fabricated using metal cores having laser drilled holes. Work will also continue to optimize the laser drilling process so that "slag" residue is eliminated.

D. ELECTRICAL FEEDTHROUGH INSULATOR

The glass insulator of the metal core feedthrough is one of the critical materials required for development of a high yield manufacturing process for 2-sided LTCC-M substrates. The insulator must exhibit the following quantities:

- Good wetting at the glass/metal interface
- High adhesion to the metal core
- Compatibility between center conductor, glass insulator, and metal core
- Stability through subsequent LTCC-M firing steps

To attain a reliable feedthrough insulator, many types of approaches were tested during the February - May 1994 time frame. These approaches are listed in Table I-1. The insulation scheme for this feedthrough relies on multiple layers of

Table I-1: Insulation Approaches Tested

1. Suction filling using screen printer
2. Electrophoresis (masked and unmasked holes)
3. Via fill using traditional screen printing techniques, dry and punch
4. Doctor blade slurry into hole, dry, and punch
5. Force green tape plug into hole and then punch
6. Laminate punched green tape sheets on top & bottom of hole
7. Electroless plated center conductors
8. Insertion of a pin into an insulated hole

dielectric insulation, as illustrated in Figure I-1. Thus, a defect in a single layer will not readily propagate through the entire insulator, causing a manufacturing defect (i.e., "shorted" feedthrough). As shown in Figure I-1, the Ni-plating on the metal core is first oxidized at 820°C, producing a tough, uniform oxide layer that exhibits resistance of 10^8 - 10^9 Ω. On top of this, multiple layers of insulating glass are deposited and fired.

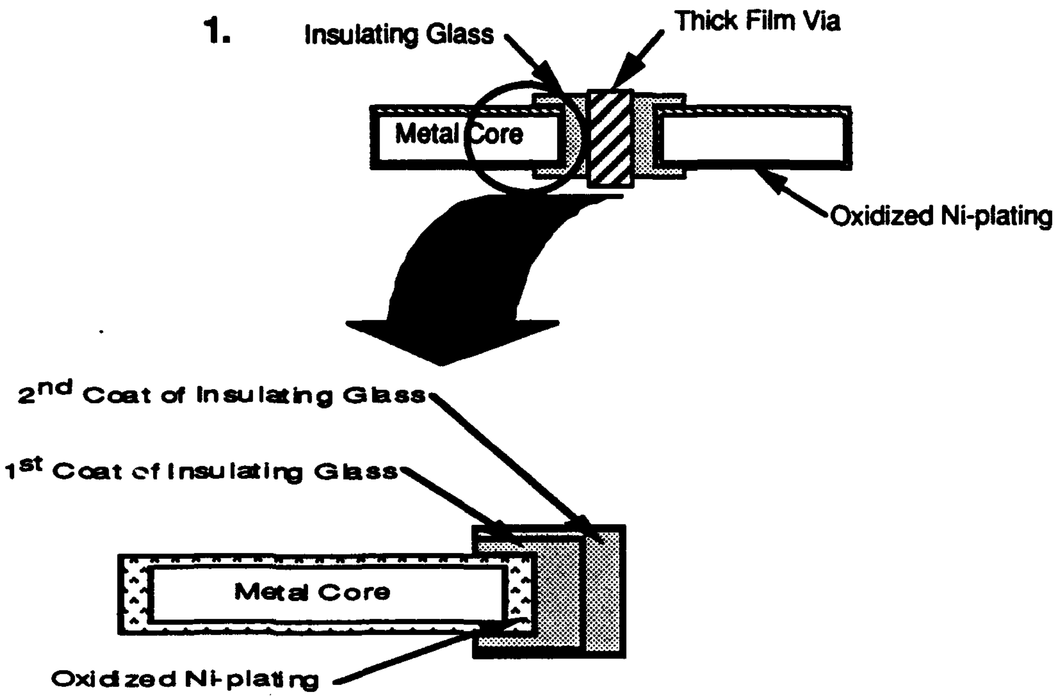


Figure I-1: Feedthrough insulation scheme using multiple layers of insulation.

Insulator Deposit Process

After testing all of the approaches shown in Table I-1, it was decided that use of a suction screen printing process would be the best way to produce a large number of reliable feedthroughs in the metal core with a high manufacturing yield in a cost effective manner. Furthermore, this process does not require any additional types of equipment beyond what is required for standard LTCC-M process.

The steps in the suction screen printing process are illustrated in Figure I-2. First, a dielectric thick film paste (of appropriate rheology) is screen printed over the hole. After the screen printer squeegee has completed its stroke, a vacuum is applied underneath the metal core, to suck the dielectric ink down the hole forming an annular ring. The part can then be removed from the screen printer for drying. To produce an insulating pad, as shown in Figures I-3 and I-4, after drying the metal core was turned over and suction printed on the bottom side. The metal core was then fired in air using a standard thick film firing profile. This process can be repeated if additional coats of insulation are desired. Finally, the thick film silver center conductor is deposited using standard via fill screen printing techniques. To form a capture pad on both sides of the metal core, after drying the metal core can be turned over and printed before firing.

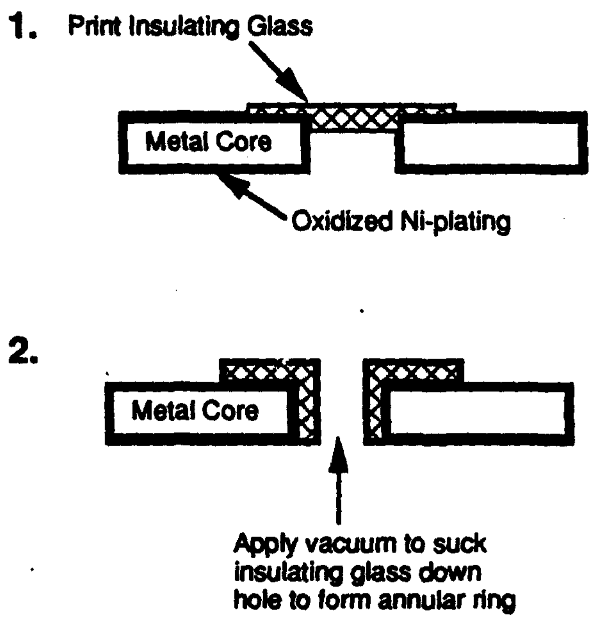


Figure I-2: Schematic illustration of suction screen printing of insulation.

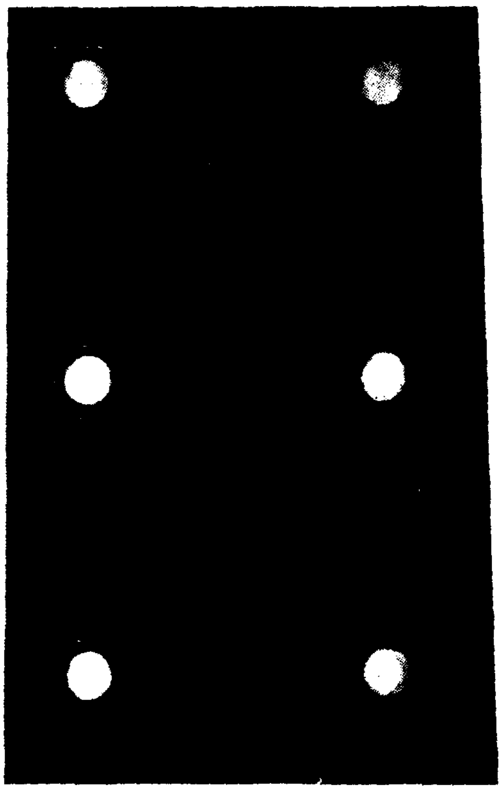


Figure I-3: Group of electrical feedthroughs in a Cu/Mo/Cu core on 200 mil centers

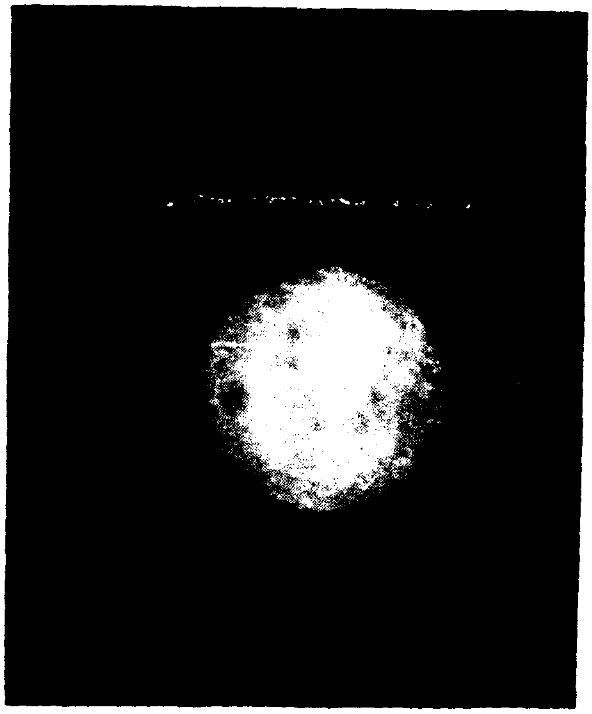


Figure I-4: Enlarged view of an electrical feedthrough with a 50 mil square insulating pad and a 30 mil diameter contact pad

The basic feedthrough process steps are summarized in Figure I-5. A cross section of a 13 mil diameter electrical feedthrough in a 20 mil thick Cu/Mo/Cu metal core is shown in Figure I-6. Figure I-7 shows a scanning electron micrograph of a portion of the cross-section of Figure I-6. These figures show that the electrical feedthrough materials system components are quite compatible with each other. In particular, the glass/metal interfaces show excellent wetting characteristics, required for high yield processing.

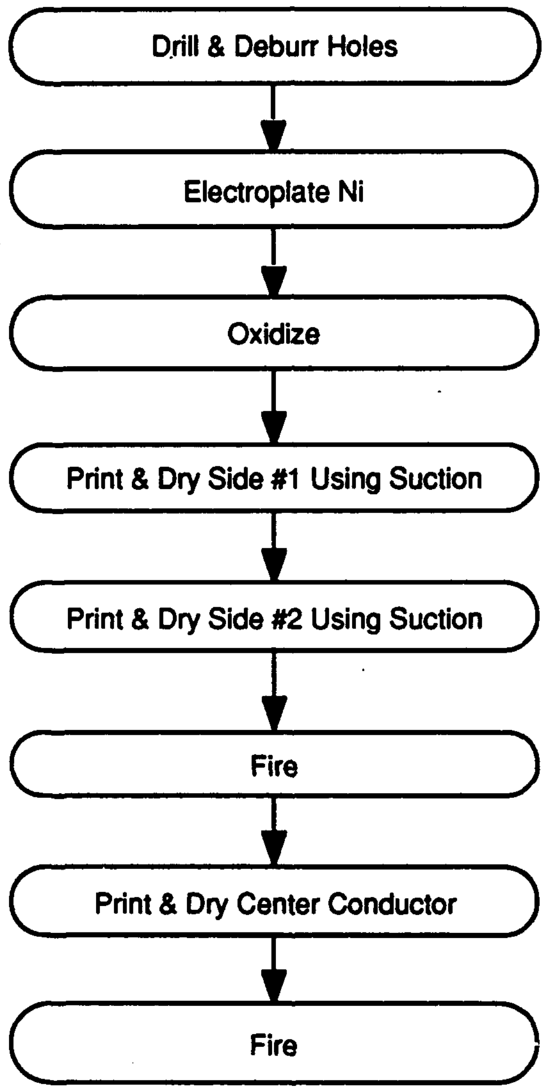


Figure I-5: Process steps for the mass fabrication of electrical feedthroughs in a Cu/Mo/Cu core.

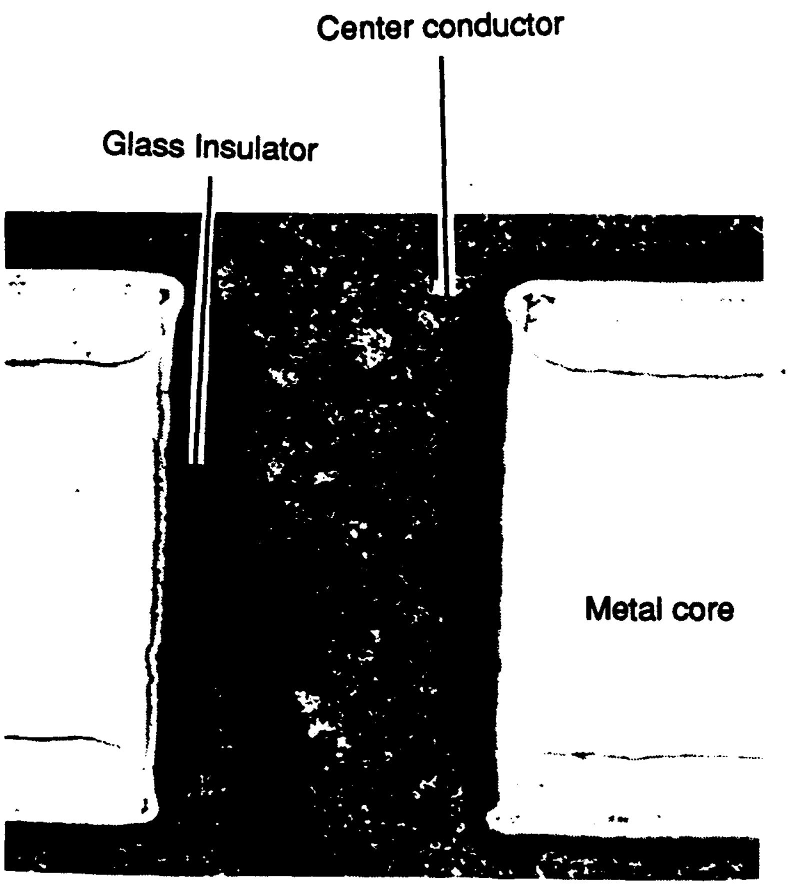


Figure I-6: **Cross section of a 13 mil diameter feedthrough in a 20 mil thick Cu/Mo/Cu metal core**

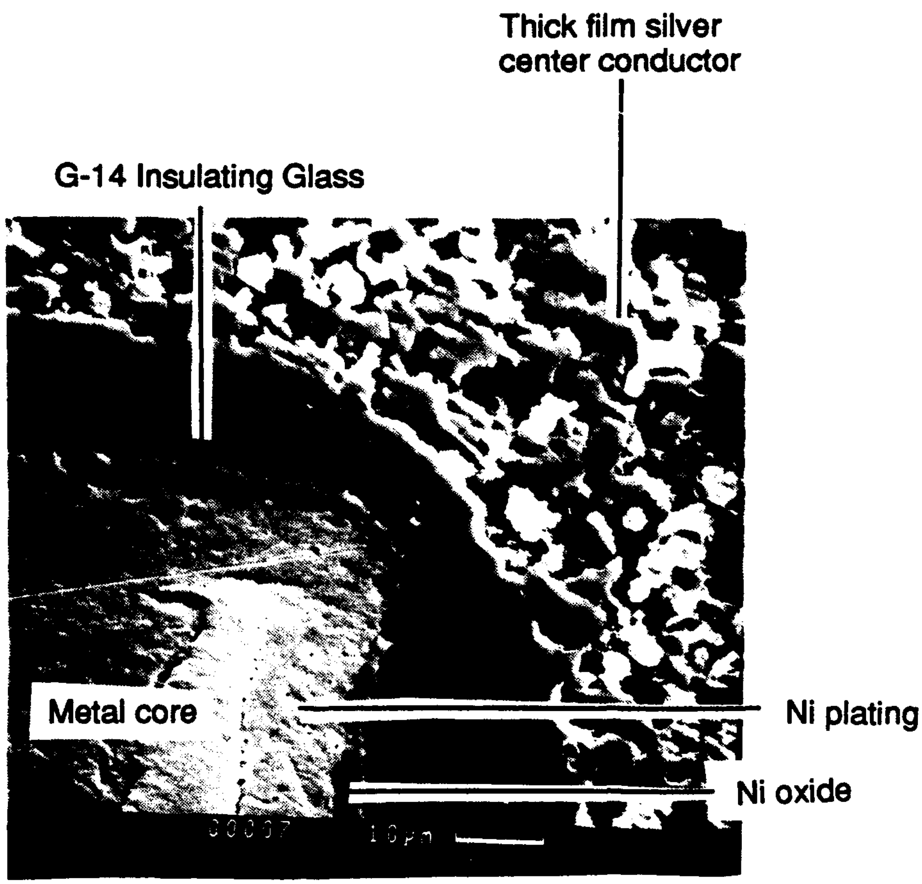


Figure I-7: **Scanning Electron Micrograph of an electrical feedthrough in Cu/Mo/Cu metal core**

Feedthrough Insulating Glass Development

The glass insulator must meet the following requirements:

- Thermal expansion matched to metal core (Cu/Mo/Cu, 13/74/13 ratio)
- Good adhesion to oxidized Ni-plating
- Good wetting of oxidized Ni-plating
- High temperature reheat stability

During the past quarter a number of glasses were surveyed. These included both vitreous and crystallizing glasses. A glass formulation, designated G-14, has been chosen as the insulating glass. As shown in figure I-8, the thermal expansion of this glass is well matched to Mo (CTE ~5 ppm/°C). G-14 is a crystallizing glass having the divitrification kinetics shown in Figure I-9. X-ray diffraction measurements indicate that willemite (ZnO-Al_2O_3-SiO_2) forms above 800°C.

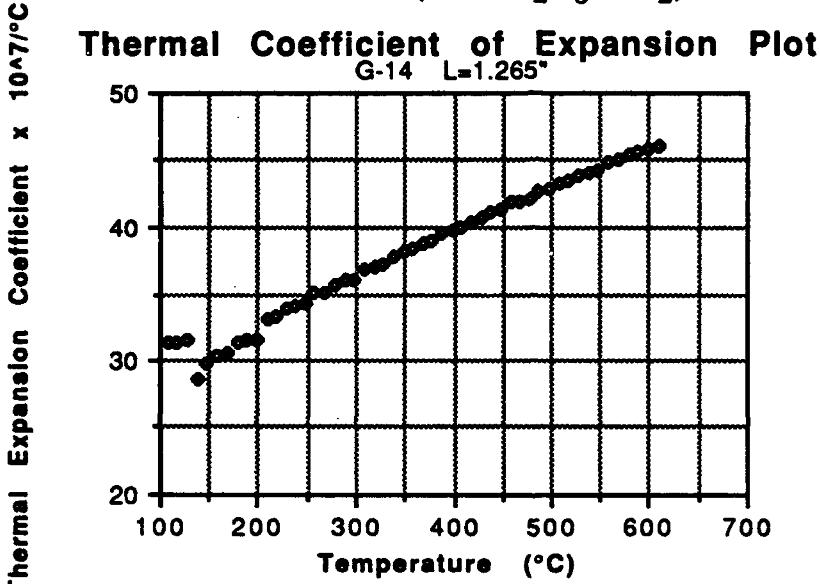


Figure I-8: Thermal expansion data of glass G-14

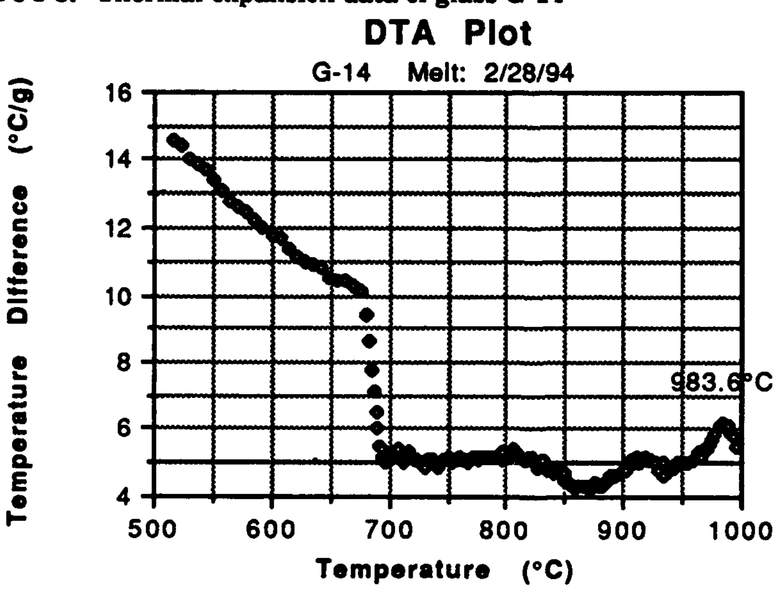


Figure I-9: Differential Thermal Analysis data for glass G-14.

E. ELECTRICAL FEEDTHROUGH CENTER CONDUCTOR

The primary requirements that the center conductor must meet are as follows:

- good electrical conductivity
- low cost metallurgy
- compatibility with insulator and metal core
- reheat stability
- compatible with LTCC-M materials
- proper rheology for complete filling

The center conductor is a silver thick film ink designed for filling using standard thick film via filling techniques. The thick film ink contains the following components:

- silver powder
- crystallizing glass G-14
- organic vehicle

F. ELECTRICAL PROPERTIES OF FEEDTHROUGHS

The leakage resistance of the feedthroughs described above is approximately $10^9 \Omega$. Twenty Cu/Mo/Cu metal cores (20 mil thick) have been fabricated, each core having 36 (13 mil diameter) electrical feedthroughs. As shown in Figure I-10, nearly all these feedthroughs have been acceptable. Each and every feedthrough exhibited electrical continuity. The few feedthroughs that were not acceptable exhibited a leakage resistance to the metal core of 10^5 - 10^6 Ω. It is thought that this was due improperly removed burrs at the hole edge, that caused thin spots in the insulating glass. Proper chamfering of the holes is expected to alleviate this problem. Such experiments will be performed next quarter with laser drilled holes.

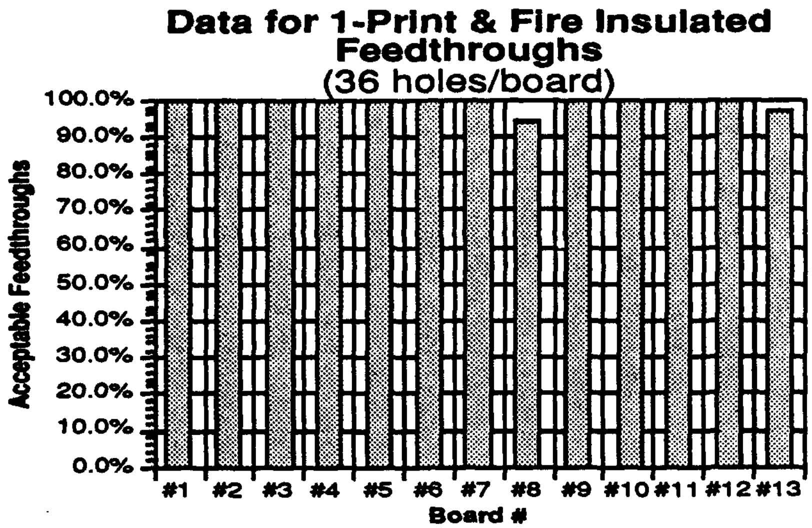
G. THERMAL SHOCK TESTING

Four metal cores (20 mils thick) having 13 mil diameter holes were subjected to 25 thermal shock cycles. The thermal shock cycle was as follows:

1. Insert board into -77°C bath (dry ice plus acetone) for 15 minutes.
2. Remove board from bath and equilibrate to room temperature in a dry box.
3. Insert board into a +150°C oven for 15 minutes.
4. Remove board from oven and equilibrate to room temperature in a dry box.

After 25 thermal shock cycles, the following results were observed.

- No opens (four boards having one-coat insulated feedthroughs) were observed
- Insulation resistance remained ~10^9 Ω
- No cracking of the exposed portion of the insulation pads.



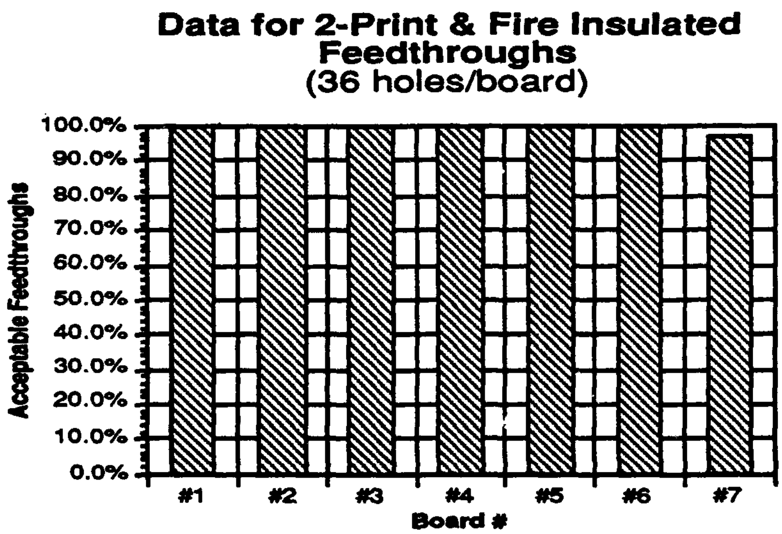


Figure I-10: **Feedthrough data for 13 mil diameter holes in 20 mil thick Cu/Mo/Cu metal cores**

H. PLAN FOR NEXT QUARTER

- Laser drilling holes in Cu/Mo/Cu will continue with the aim of eliminating the "slag residue that is formed
- Chamfering experiments will be performed to eliminate the occasional "shorted" center conductor
- Electrical feedthroughs will be made in metal cores having laser drilled holes

Section II
WBS Task 1.2: LTCC Ceramic Development

A. TASK OBJECTIVE

The development of suitable ceramic compositions for use as an inter-layer dielectric of a substrate having high density multilayer wiring. The ceramic will be processed into a green tape for the fabrication of high reliability modules using low cost processing techniques.

B. INTRODUCTION

In the last reporting period we had outlined the work needed for the development of suitable glass ceramic dielectrics for the ASEM project. The required properties in the dielectric material, the methods for their assessment, and the criteria for selection had been discussed. We also had reported on the development of a group of glass-ceramic compositions that were potentially suitable for the ASEM application. Having now completed the evaluations of these potential candidates, we have selected one composition for use in the next phase of the project. In this report we will discuss the choice of this particular glass-ceramic material.

C. GLASS-CERAMIC COMPOSITIONS

About thirty glass ceramic compositions were formulated and evaluated to varying degrees for suitability for LTCC-M substrate fabrication on Cu/Mo/Cu metal base using silver conductor inks. Ten of these compositions were based on mixtures of powdered glass and ceramic, while the remainder were crystallizable glasses with no filler. Of these the best behaved compositions with respect to sinterability, thermal expansion matching to Cu/Mo/Cu .cores, and dielectric properties were found among the crystallizable glasses. In particular, three compositionally-related glasses designated as KU-4, KU-5 and KU-7 were identified as the potential candidates and, after further evaluation, KU-4 was picked as the prime candidate dielectric for the ASEM project.

D. KU-4 GLASS-CERAMIC

Composition :

The KU-4 glass is a MgO-Al_2O_3-SiO_2 composition lying in the area of the ternary phase diagram as shown in Figure II-1. This position on the phase diagram indicates that the major, equilibrium phases in the crystallized glass should be clino-enstatite and cordierite. In addition to the major oxides, the glass contains small amounts of other glass formers and nucleating agents to influence its crystallization behavior. Glasses KU-5 and KU-7 are modifications of the KU-4 glass to obtain desired sintering and thermal expansion behaviors.

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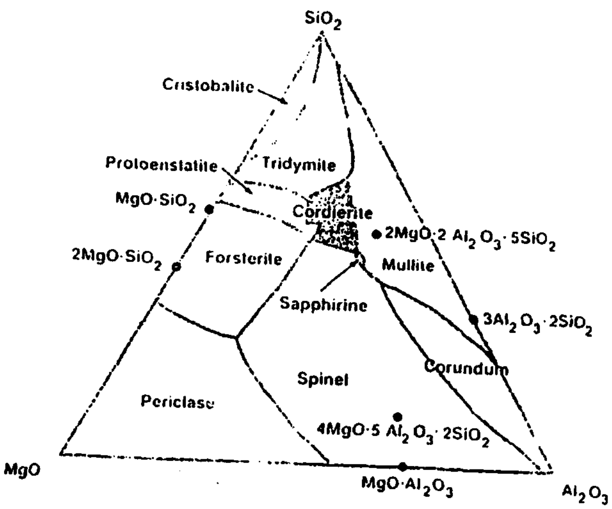
Figure II-1



Cordierite glass compositions

DTA and sintering characteristics:

The differential thermal analysis (DTA) plot of KU-4 glass is shown in Figure II-2. Barring a tendency towards premature crystallization, the DTA indicates that the glass powder should sinter by coalescence in the temperature range between 875°C and 925°C. The well defined single crystallization peak at 960°C is believed to represent the direct crystallization of the glass to a-cordierite and enstatite.

Thermal coefficient of expansion :

The room temperature thermal coefficients expansion (CTE) of glass-ceramics in the MgO-Al_2O_3-SiO_2 has been previously shown to vary with composition in a predictable manner reflecting the relative proportions of the enstatite and alpha-cordierite in the fully crystallized glass-ceramic body. The CTE of KU-4 was [illegible]nd to lie close to the value indicated by the extrapolation of previous data o[illegible] er cordierite glass-ceramics as seen in Figure II-3. This provides an assuran[illegible] at this glass is well behaved in its CTE characteristic.

The CTE of KU-4 is compared to that of molybdenum over a wide range of temperature in Figure II-4. Below about 400°C, the CTE of the crystallized glass is lower than that for molybdenum while above this temperature it is higher than that of molybdenum, the difference between the two steadily increasing with temperature. Over the entire temperature range, which substantially covers the sintering range, the total thermal contraction of the glass-ceramic and molybdenum appear to be nearly equal.

The thermal expansion of the glass-ceramic depends upon the peak sintering temperature, whereas the exact thermal expansion curve for the Cu-Mo-Cu cores will depend on the relative thicknesses of Cu and Mo in the composite core. KU-4 sintered at peak sintering temperature of 900°C (30 minutes at peak temperature) had a room temperature CTE value of 56 ppm/°C, while that sintered at 915°C (30 mins) had a room temperature CTE value of 46 ppm/°C. This clearly reflects the degree of crystallization of the glass, as will be evident from the microstructures shown later.

Exact thermal expansion matching of the core and the glass-ceramic is vital to the fabrication of LTCC-M substrates with acceptable camber and good structural integrity. Exact matching does not mean point-to-point CTE matching over the entire sintering temperature range. Rather, it means that the total thermal contraction of the glass-ceramic from the setting temperature of the glass (i.e. temperature below which no stress relaxation occurs by viscous deformation of the glass) should equal the thermal contraction of the metal core over the same temperature range. We believe that the degree of CTE matching of KU-4 and Cu-Mo-Cu that now exists is adequate for developing the glass-ceramic-to-core bonding process. This is apparent from the small degree of camber we have observed in the LTCC-M parts prepared on Cu-Mo-Cu cores. Once the bonding method is optimized, further fine tuning of the thermal expansion of the glass-ceramic will be needed. This can be accomplished either by small variations in the peak firing temperature, time at temperature, or by small modifications of the glass-ceramic composition.

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Figure II-2

DIELECTRIC GLASS
2. Differential Thermal Analysis

1 : Glass Transition 850 °C
2 : Sintering Range 875 ° - 925 °C
3 : Peak Crystallization 960 °C

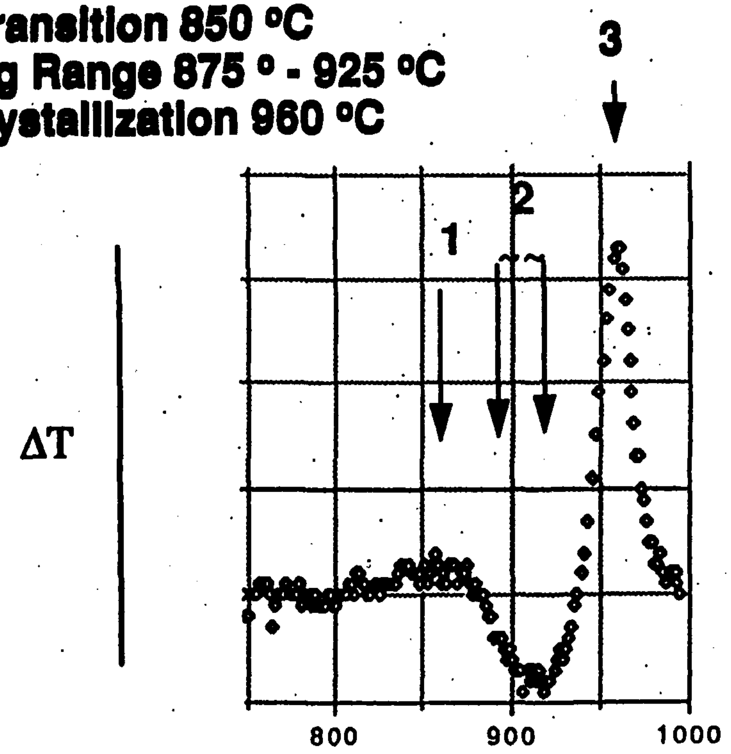

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Figure II-3

THERMAL EXPANSION TAILORABILITY

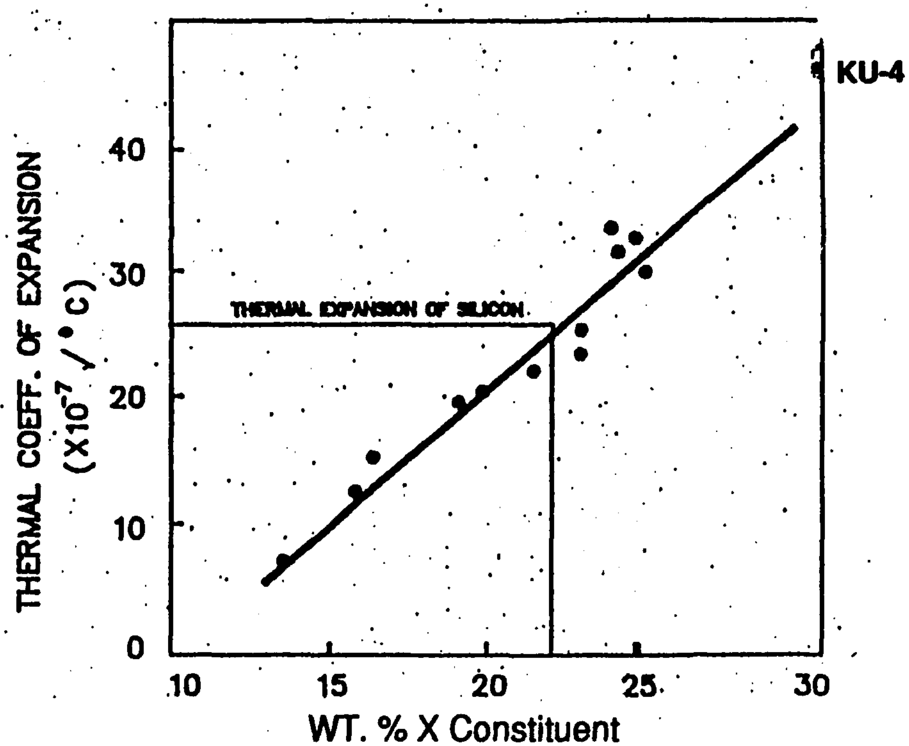

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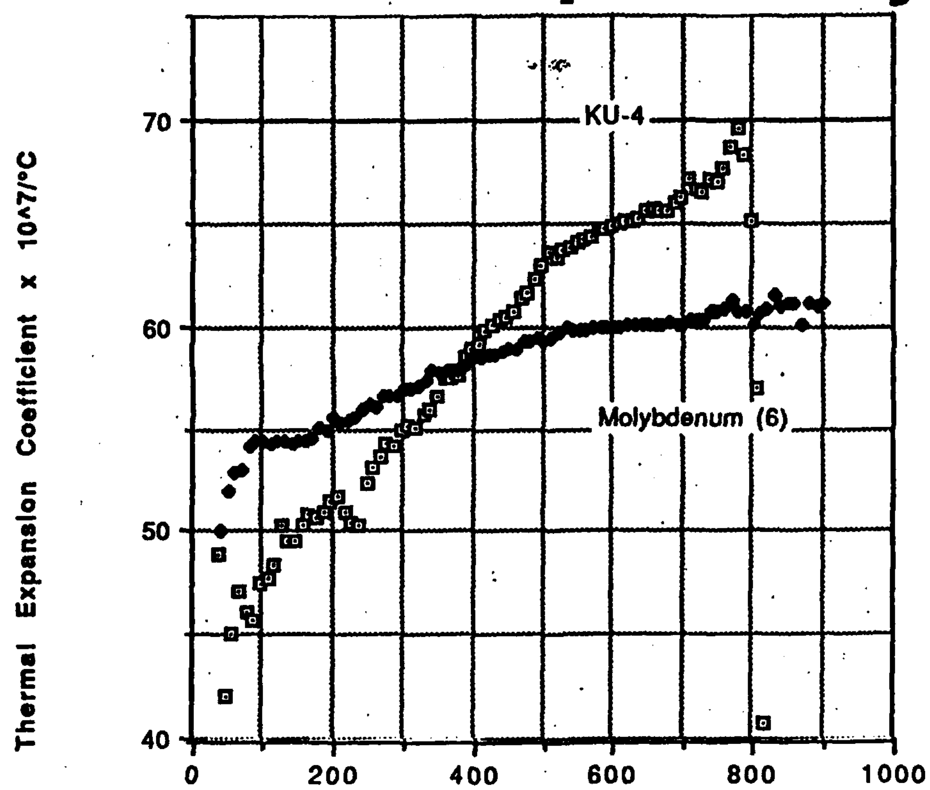
Figure II-4

DIELECTRIC GLASS

1. Thermal Expansivity



- Exact thermal expansivity matching to Cu-Mo-Cu can be achieved by fine tuning composition and/or thermal treatment

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Dielectric Properties:

From the outset, the dielectric martial development was geared towards developing glass-ceramic materials that were suitable for both high speed digital and microwave applications. This translated into dielectric's having low dielectric constants and very low loss values at microwave frequencies. We are happy to report here that KU-4 and KU-5 glass-ceramics have low dielectric constants and have loss values that meet or exceed those for comparable materials developed for microwave substrate applications. The dielectric data for these two glasses are summarized in Table II-1. As with the CTE , both the dielectric constant and tanδ values are high for samples sintered at 900°C. The values decrease dramatically in samples heat treated at 915°C. This drop is associated with the higher degree of crystallization in the samples heat treated at 915°C.

Microstructure:

The dramatic changes in the CTE and dielectric properties of the glass-ceramic KU-4 are reflected in the of the KU-4 samples fired at 900°C and 915°C. shown in Figure II-5. In the sample fired at the lower temperature, the microstucture consists of predominantly glassy areas interspersed with areas where crystallization. In the sample fired at 915°C abundant and uniform crystallization is evident. Another noteworthy feature observed was the near absence of porosity in the sintered parts.

Co-firing with silver:

Several 6-layer parts, with circuit patterns formed with off-the-shelf thick film silver ink, were fired in air to assess any tendency for silver to bleed into the dielectric during firing. Such silver bleeding, which often manifests itself as a yellow discoloration of the ceramic, indicates an interaction between the silver and the ceramic. Both KU-4 and KU-5 parts with silver patterns showed little or no yellow discoloration

Acid resistance:

It is possible that the bonding pads on the surface of the substrates will require electroless plating of nickel and/or gold. Hence it is necessary that the dielectric martial chosen for the substrate application be resistant to leaching in the plating solutions. In particular, the highly acidic nickel bath (pH = 5) is a source of concern. KU-4 glass-ceramic was dipped in the nickel bath for an hour and examined for any leaching. No leaching was observed.

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Table II-1

DIELECTRIC GLASS
3. Dielectric Properties

- ***DIELECTRIC CONSTANT AND LOSS DEPEND ON PEAK SINTERING TEMPERATURE***

Peak Sintering Temperature ºC	k (15 GHz)	tan δ (15 GHz)
900	6.9	12.7×10^{-3}
925	5.7	1.6×10^{-3} *

* ***Lowest high frequency loss value reported in LTCC materials***

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Figure II-5

DIELECTRIC GLASS
6. Microstructure

Mag=2000

Peak Sintering 900 °C
Highly Glassy
TCE = 56 x 10 $^{-7/}$ °C
k = 6.9, tan δ = 12.7 x10 $^{-3}$

Peak Sintering 915 °C
Highly Crystalline
TCE = 46x $^{-7}$ °/C
k=5.7, tan δ = 1.6 x10^{-3}

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E. PLAN FOR NEXT QUARTER

- In the next reporting period we will undertake a more detailed characterization of the dielectric KU-4. This will include x-ray diffraction analysis for identification of crystalline phases, characterization of the sintering and crystallization kinetics including the role of particle size on these changes, batch to batch consistency of DTA, CTE, and modulus of rupture measurements on free-sintered parts.
- During this period we will also fine tune the CTE of the ceramic to obtain camber-free LTCC-M parts.
- Another important area of work in this period will be the development of glazes and thermal treatments needed to achieve zero-shrinkage locking of the ceramic substrate to nickel-plated and oxidized Cu/Mo/Cu cores.

Section III
WBS Task 1.4: Thin Film Interconnect Structure Integration

A. TASK OBJECTIVE

The objective of this part of the program is to demonstrate that MCM-D interconnect structures can be built on top of the ASEM ceramic substrate. This will be accomplished by the actual fabrication of a multi-level, thin film interconnect structure on the final ASEM test vehicle and subjecting this structure to the relevant reliability tests.

B. RESULTS TO DATE

At present we are trying out various methods and polymeric dielectrics in preparation for the for the eventual fabrication of thin film interconnect structures on the ASEM Demonstration Vehicle. Previously we had reported on methods for thin film interconnect fabrication that utilized either a photosensitive or a non-photo-sensitive polyimide dielectric. In this reporting period we have fabricated such interconnects utilizing benzo-cyclo-butene polymer (BCB) made by Dow Chemical Corporation. BCB has several advantages over polyimides that are listed in Table III-1.

TABLE III-1:
Comparison of BCB and Polyimide Polymer overlay Processing

BCB	Polyimide
• Metal mask needed	• Photodefinable
• Developer not required	• Special developer and rinse
• Strippable when cured	• Strippable either cured or uncured
• Simple cure cycle	• 3-step cure
• Not hygroscopic	• Hygroscopic
• Excellent planar coverage (>80%)	• Poor planar coverage (<20%)
• Barrier layer not required with copper	• Barrier layer needed with copper

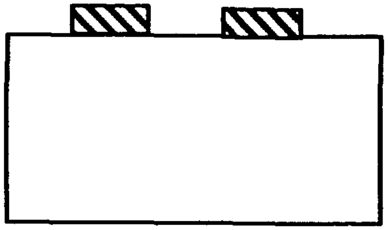
The interconnect structures were fabricated using recently acquired, three level mask set, specially designed for assessing feature dimension capabilities and yields of the interconnect structure. The processing method employed is shown schematically in Figure III-1. The via etching was carried out using an integral metal mask fabricated on top of the BCB layer. We have recently obtained Cyclotene™, a version of BCB that can be wet etched through a photoresist mask, greatly simplifying the thin film process.

C. PLAN FOR NEXT QUARTER

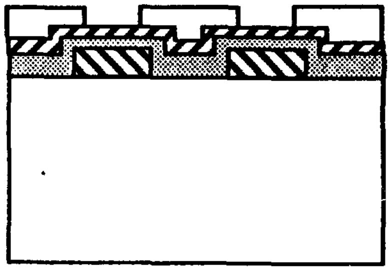
- Next quarter interconnect structures will be fabricated using Cyclotene™.

Figure III-1

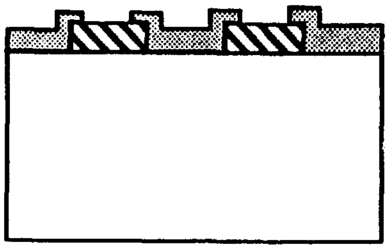
BCB Via Fabrication



- Sputter deposit Cr-Cu
- Apply photoresist and expose line pattern
- Electroplate Cu-Au lines
- Remove unwanted seed layer by ion milling



- Coat with BCB and cure
- Sputter deposit 2000Å Cu
- Apply photoresist and expose via pattern



- Etch via pattern in copper by ion milling
- Etch via pattern in BCB by plasma etching
- Strip Cu mask in 50% Nitric acid

VAP 5/23/94

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Section IV
Important Findings

A. ELECTRICAL FEEDTHROUGHS

A low cost process for the mass fabrication of small (13 mil diameter) in a Cu/Mo/Cu metal has been demonstrated. To assure a high yield process, multiple layers of insulator formed, so that it is highly unlikely that a defect in one insulation layer will propagate to the next layer. The process relies on suction screen printing (a variation of standard via-filling by screen printing methods) to form a reliable insulator. An crystallizing glass, G-14, was found to exhibit all of the properties necessary for fabricating a reliable insulator with high manufacturing yield. The center conductor is subsequently formed by standard screen printing techniques. The process forms electrical feedthroughs that are isolated from the metal core by $>10^9\Omega$. Thermal shock testing (25 cycles) between -77°C and +150°C did not cause any opens in the feedthroughs, and the isolation from the metal core remained $10^9\Omega$. Laser drilling the holes in the metal core shows great promise, which will greatly reduce the both the drilling time and the cost of fabricating electrical feedthroughs.

B. LTCC-M CERAMIC DEVELOPMENT

A glass ceramic, KU-4, was chosen to be the prime candidate for development of the green tape system for this project. KU-4 glass is a $MgO-Al_2O_3-SiO_2$ composition that readily crystallizes above 915°C. This glass is thermal expansion matched to the Cu/Mo/Cu (13/74/13 ratio) metal core and exhibits very low dielectric loss, making it an ideal substrate material for interconnecting bare Si and GaAs die in high speed digital and microwave circuits.

Section V
Significant Developments

To insure that the processes under development are indeed cost effective, a preliminary cost analysis was performed on the technology being developed during Phase I of this project. This cost analysis indicated that the high volume manufacturing of a single-sided, 6-layer LTCC-M substrate on a Cu/Mo/Cu metal core providing 200 inches/sq. in. of interconnect density will be about $1.43/sq. in.; in comparison, the low cost MCM-L technology would cost $1.50/sq. in. and still not provide a metal base for thermal management. Projecting to a 2-sided substrate having 6-layers on each side, a 400 inch/sq. in. interconnect density would cost about $2.39. This technology is well on target to meet ARPA's 1996 goal of producing interconnect substrates having an interconnect density of 1000 inches/sq. in. for $10/sq. in.

Section IV
Plan for Further Research

The major emphasis for the upcoming quarter will be to develop a bonding layer process for firing the KU-4 based green tape onto the metal core with "zero" shrinkage.

Electrical Feedthrough Development

- Laser drilling holes in Cu/Mo/Cu will continue with the aim of eliminating the "slag residue that is formed
- Chamfering experiments will be performed to eliminate the occasional "shorted" center conductor
- Electrical feedthroughs will be made in metal cores having laser drilled holes

LTCC-M Ceramic Development

- In the next reporting period we will undertake a more detailed characterization of the dielectric KU-4. This will include x-ray diffraction analysis for identification of crystalline phases, characterization of the sintering and crystallization kinetics including the role of particle size on these changes, batch to batch consistency of DTA, CTE, and modulus of rupture measurements on free-sintered parts.
- During this period we will also fine tune the CTE of the ceramic to obtain camber-free LTCC-M parts.
- Another important area of work in this period will be the development of glazes and thermal treatments needed to achieve zero-shrinkage locking of the ceramic substrate to nickel-plated and oxidized Cu/Mo/Cu cores.

Thin Film Interconnect Structure Integration

- Next quarter interconnect structures will be fabricated using Cyclotene™.

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The quarterly progress for the Ceramic/Metal Composite Circuit-Board-Level Technology for Application Specific Electronic Modules is described in this report. Data is reported for the following tasks: Metal Core Fabrication, LTCC Ceramic Development, and Thin Film Interconnect Structure Integration.

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